5A-4
6th Asia-Oceania Symposium on Fire Science and Technology
17-20, March, 2004, Daegu, Korea

Feasibility Study of Use of Elevators in Fire Evacuation in a High-rise Building

A. Sekizawa[1], S. Nakahama[2], H. Notake[3], M. Ebihara[1], and Y. Ikehata[2]

[1] *Fire and Disaster Management Engineering Laboratory, Graduate School of Engineering, The University of Tokyo, Tokyo, Japan*
[2] *Technology Center, Taisei Corporation, Totsuka-ku, Yokohama, Kanagawa, Japan*
[3] *Institute of Technology, Shimizu Corporation, Etchujima, Koto-ku, Tokyo, Japan*

Abstract

In many past fires, not a few people used elevators for their evacuation, although they are told to escape by stairs in emergency. Also, it is expected that the number of people who have difficulty to use stairs in evacuation would become larger, since the proportion of aged people in the total population has been rapidly increasing recently and also accessibility of disabled people has been improved in Japan. To consider this situation, we made a simplified model to evaluate evacuation time by elevators, and conducted some case studies in order to examine the feasibility and issues of elevator use for evacuation. As the result of case studies, if the elevator use group can be designated only for a small part of occupants such as disabled people, it would be effective to use elevator in evacuation for those people. However, for other general people, it would be better to use stairs for their evacuation in most cases as well as to let the evacuation of disabled people by elevator more effective.

1. Introduction

At the situation of a building fire, occupants are told that they should escape to the ground level or a floor of refuge by stairs, but not by elevators. However, in fact in many past fires, not a few people used elevators for their evacuation. For example, in the fire of 20-story Hiroshima Motomachi High-rise Apartments that occurred in October 28, 1996 in Japan, more than a half of the total evacuees used elevators from the results of our questionnaire survey[1)]. On the other hand, the number of people who have difficulty to use stairs becomes larger year by year in high-rise buildings, since the proportion of aged people in the total population has been rapidly increasing and also accessibility of disabled people has

Corresponding Author- Tel.: +81-3-5841-725;
Fax: +81-3-5841-7327
E-mail address: sekizawa@chemsys.t.u-tokyo,ac,jp

been improved recently in Japan. Therefore, the potential demand of elevator use in evacuation has been growing recently especially after the WTC collapse on September 11th, 2001, while evacuation using elevators in case of a fire is still a controversial issue because the safe operation of regular elevators is not always secured during evacuation in a fire. In the context of this situation, we developed a simplified model to simulate the elevator operation for calculating evacuation time by elevators and we conducted some case studies with this elevator service model to examine the feasibility and issues of elevator use for evacuation mainly from the viewpoint of its efficiency of transportation of occupants rather than fire safety aspect during the operation.

2. Models for Evacuation by Elevator and by Stairs

2.1 Models of elevator service operation for evacuation

For the case study of elevator use in evacuation in a high-rise office building, we revised the former model[2),3)] in order to handle the operation of multiple elevators. In this section, the outline of the new model of elevator operation is described hereafter. Using this model, we can change the performance of each elevator such as its speed and/or capacity as well as the priority of floors that each elevator goes to independently in order to examine quantitatively both the performacne and the applicable strategy of elevator use in evacuation. By the way, to calculate the elevator travel time, we should consider the stages of elevator movement such as "stop", "acceleration", "constant velocity", "deceleration", and "stop" again. **Figure 1** shows the schematic diagram for describing the relationship of these stages. Also, we should consider three patterns of elevator movement to calculate travel time of elevators. The first pattern is that an elevator movement has a stage of the constant velocity like the case in **Figure 1**. The second pattern is that an elevator decreases its velocity immediately after reaching the constant velocity, and the third pattern is that an elevator decreases its velocity before reaching the constant velocity as shown in **Figure 2**. The process of how to calculate the travel time in each pattern is described below in (1), (2), and (3).

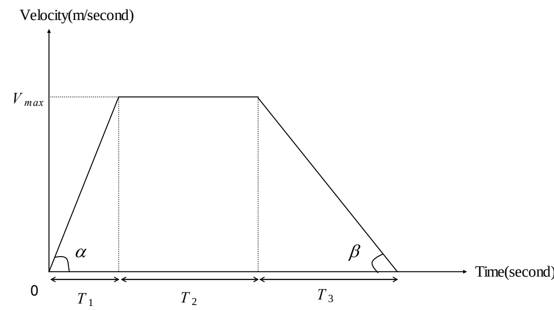

Figure 1 Schematic diagram for calculating elevator travel time for the pattern that an elevator movement has a stage of the constant velocity (V_{max}).

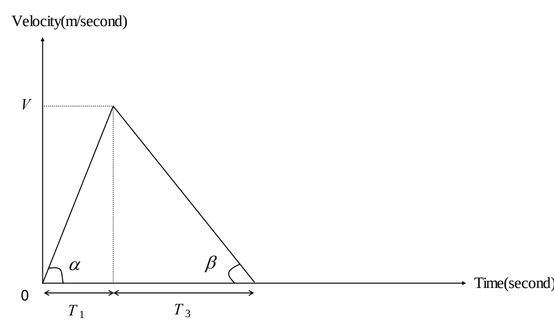

Figure 2 Schematic diagram for calculating elevator travel time for the pattern that an elevator decreases its velocity before reaching the constant velocity.

(1) The pattern that an elevator movement has a stage of the constant velocity.

The vertical distance for the elevator movement is calculated by the following equations.

$$L = \frac{1}{2}\alpha T_1^2 + V_{\max} T_2 + \frac{1}{2}\beta T_3^2 \quad \text{-------------- [1]}$$

$$V_{\max} = \alpha T_1 = \beta T_3 \quad \text{---------------------------- [2]}$$

Where,

- L : vertical distance for the elevator movement (m)
- α : elevator acceleration (m/s^2)
- β : elevator deceleration (m/s^2)
- $V_{\max}$: maximum elevator velocity (m/s)
- T_1 : acceleration time (s)
- T_2 : constant velocity time (s)
- T_3 : deceleration time (s)

From equation [1] and [2], we can lead the following equations.

$$T_1 = \frac{V_{\max}}{\alpha} \quad \text{------------------------------------- [3]}$$

$$T_3 = \frac{V_{\max}}{\beta} \quad \text{------------------------------------ [4]}$$

$$T_2 = \frac{\left(L - \frac{V_{\max}{}^2}{\alpha} - \frac{V_{\max}{}^2}{\beta}\right)}{V_{\max}} \quad \text{--------------- [5]}$$

Then, we can calculate the total elevator travel time (T_{total}) by the following equation.

$$T_{total} = T_1 + T_2 + T_3$$

$$= \frac{V_{\max}}{\alpha} + \frac{\left(L - \frac{V_{\max}{}^2}{\alpha} - \frac{V_{\max}{}^2}{\beta}\right)}{V_{\max}} + \frac{V_{\max}}{\beta} \quad \text{-- [6]}$$

(2) The pattern that an elevator decreases its velocity just after reaching the constant velocity.

In this case, T_2 = 0, which means the equation [5] is zero. So, substituting T_2 = 0 in equation [6], the total elevator travel time is represented by the following equation.

$$T_{total} = \frac{V_{\max}}{\alpha} + \frac{V_{\max}}{\beta} \quad \text{--------------------- [7]}$$

(3) The pattern that an elevator is decreasing its velocity before reaching the constant velocity.

The relation between the velocity (V) at the time of changing from acceleration stage to deceleration stage and the acceleration stage as well as the deceleration stage is represented by the following equation.

$$V = \alpha T_1 = \beta T_3 \quad \text{-------------------------- [8]}$$

And, substituting T_2 = 0 in the equation [1] and using the equation [8], we can lead the following equation.

$$L = \frac{1}{2}\alpha\left(\frac{V}{\alpha}\right)^2 + \frac{1}{2}\beta\left(\frac{V}{\beta}\right)^2$$

$$= V^2\left(\frac{1}{2\alpha} + \frac{1}{2\beta}\right) \quad \text{------------------- [9]}$$

Using equation [8] and equation [9], we can calculate the total elevator travel time by the following equation.

$$T_{total} = T_1 + T_3$$

$$= \left(\frac{1}{\alpha} + \frac{1}{\beta}\right)\sqrt{\frac{L}{\left(\frac{1}{2\alpha} + \frac{1}{2\beta}\right)}} \quad \text{---------- [10]}$$

2.2 Model of evacuation by stairs

In this paper, based on the assumption that evacuees use two egress stairs evenly and they start evacuation simultaneously on every floor, the evacuation time by egress stairs T_{str} is calculated as the total sum of horizontal walking time, vertical walking time, and either of larger one between passage time through the stairs and passage time through the exit door from the stairs to the first floor. T_{str} is represented by the equation [11]. The specifications and results of calculation of evacuation by egress stairs are described in **Table 1**.

$$T_{str} = \frac{L_h}{V_h} + \frac{L_s}{V_s} + \max\left(\frac{P_{str}}{(N_{str} \cdot W_{str})}, \frac{P_{str}}{(N_{xit} \cdot W_{xit})} \right)$$

-------------- [11]

Where,

T_{str} : evacuation time by stairs (s)
L_h : maximum horizontal walking distance (m)
V_h : horizontal walking speed (m/s)
L_s : maximum vertical walking distance (m)
V_s : vertical walking speed (m/s)
P_{str} : number of evacuees by stairs ($persons$)
N_{str} : average flow factor in stairs ($persons/m \cdot s$)
W_{str} : available stairs width (m)
N_{xit} : flow factor of the door on the first floor ($persons/m \cdot s$)
W_{xit} : available door width on the first floor (m)

3. Case Study

3.1 Purpose of case study

In order to examine the feasibility of elevator evacuation using a typical high-rise building, we conducted case studies with our simulation model of elevator operation and the model for evacuation by stairs, which are described in the former section in this paper. In the case studies, mainly focusing upon the efficiency of transportation of occupants rather than fire safety aspects of elevators during the operation, the following subjects are investigated.

(1) First, as the bank, where a fire occurs, changes, how does the evacuation completion time by elevators change? And, which is shorter and preferable to use emergency elevators or to use egress stairs for evacuation in the bank where a fire occurs?

(2) Second, from the viewpoint of transportation efficiency, which is preferable between two emergency operational modes of elevators such as the mode(a) that priority is given to the floors just above a fire floor first or the mode(b) that priority is given to the highest floor first?

(3) Lastly, as the ratio of elevator use in evacuation at the bank, where a fire occurs, is changing, how the evacuation time of both by emergency-use elevators and by egress stairs are affected by the ratios?

3.2 Floor configuration and the elevation of a building for case study

For doing case studies, we used a 53-story model building that has a center core system with reference to the actual high-rise office building in Japan. The floor configuration and the elevation of the building are shown in **Figure 3**.

Table 1 Specifications and results of calculation of evacuation by egress stairs.

Note: The specifications and evacuation time are obtained from the data in section 3.2.

	Whole Build.	A-Bank	B-Bank	C-Bank	D-Bank
Ratio of stair use in evacuation (*%*)	100%	100%	100%	100%	100%
Total number of occupants (*persons*)	10920	2730	2730	2730	2730
Number of egress stairs	2	2	2	2	2
Number of occupants for each stairs (*persons*) [*Pstr*]	5460	1365	1365	1365	1365
Maximum horizontal walking distance (*m*) [*Lh*]	50	50	50	50	50
Horizontal walking speed (*m/s*) [*Vh*]	1	1	1	1	1
Maximum vertical walking distance (*m*) [*Ls*]	193.15	50.8	98.25	145.7	193.15
Vertical walking speed (*m/s*) [*Vs*]	0.25	0.25	0.25	0.25	0.25
Width of each stairs (*m*) [*Wstr*]	1.2	1.2	1.2	1.2	1.2
Available width of exit door (*m*) [*Wxit*]	1.08	1.08	1.08	1.08	1.08
Flow factor of stairs (*persons/s ・m*) [*Nstr*]	1.3	1.3	1.3	1.3	1.3
Flow factor of exit door (*Persons/s ・m*) [*Nxit*]	1.5	1.5	1.5	1.5	1.5
Evacuation time by stairs (*s*) [*Tstr*]	4323	1128	1318	1508	1698

Table 2 Occupant load and elevators condition in the building for case studies.

	Unit	A-Bank	B-Bank	C-Bank	D-Bank	Emergency EV
Service floor	floor	1-14	1, 15-27	1, 28-40	1, 41-53	1-53
Number of elevators		8	8	8	8	2
Capacity	persons	22	22	22	22	32
Constant travel speed	m/s	4	5	6	7	3
Acceleration	m/s^2	0.7	0.7	0.7	0.7	0.7
Deceleration	m/s^2	-0.7	-0.7	-0.7	-0.7	-0.7
Door width	m	1.1	1.1	1.1	1.1	1.9
Occupant load on each bank	persons	2,520	2,520	2,520	2,520	-----

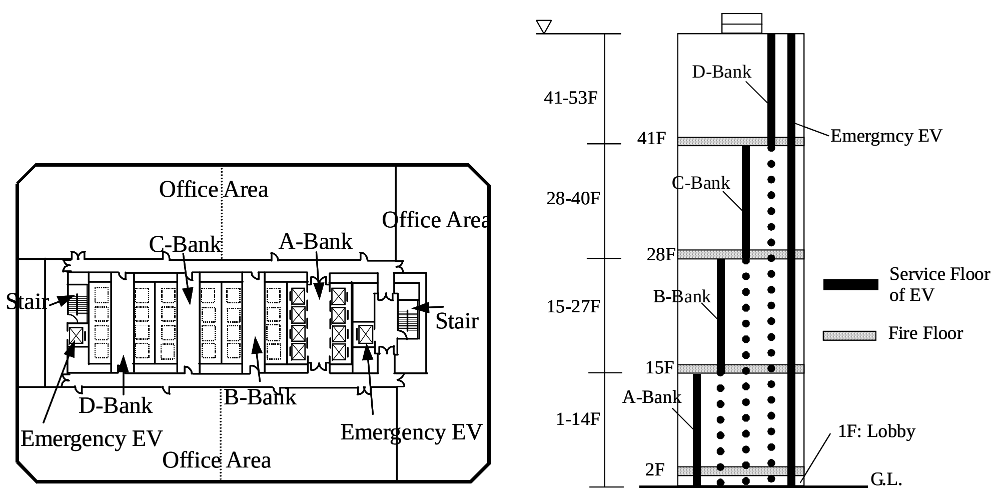

Figure 3 Floor plan and elevation of a model high-rise building for case study.

Although some stories are used as restaurants and medical clinics other than offices in the actual building, but in the case studies it is assumed that every floor is used for office space. A standard floor area is 2,629m^2 and the story height is 3.65m (only the height of the first floor is 7.0m). The floor of refuge is the first (ground) floor, which is a lobby. In the center core, there are four elevator banks for services to the corresponding four parts of floors such as a bottom part (A-Bank :1F-14F), a mid-lower part (B-Bank :15F-27F), a mid-upper part (C-Bank :28F-40F), and a top part (D-Bank: 41F-53F). Hereafter, for shortening purpose, we call each block of floors for elevator services in each bank just as A-bank, B-bank, C-bank, and D-bank respectively. In each bank, there are eight regular elevators and so the total number of regular elevators is 32.

By the way, two fire/smoke proof emergency-use elevators are installed at both east and west sides of the building. The emergency-use elevators are usually operated by building staffs as well as firefighters and they can stop at every floor. Also, for emergency evacuation such as in a fire, two fire/smoke proof egress stairs, which has a vestibule shared by the emergency-use elevators, are provided near the emergency-use elevators as seen in **Figure 3**.

For the calculation of evacuation by elevator, we assumed a fire floor on the bottom floor as a most unfavorable condition within floors of each bank. And, total occupant load in each bank and number of elevators as well as their capacity and travel speed are specified in **Table 2** according to the actual conditions in the building that is modeled. The occupant load is calculated by the equation [15].

$$P_{floor} = \rho \times A_{officearea} \quad \text{-------------------- [15]}$$

Where,

P_{floor} : number of occupants on one floor

ρ : crowd density

(office:0.125 *persons/m*^{2})

$A_{office\ area}$: office area of one floor (m^2)

3.3 Premises for case study

In case studies, we conducted the calculation of evacuation time by elevators on the following premises in consideration of the realistic and/or worst conditions in a fire situation.

1) A fire floor is assumed to be the bottom floor in each part of floors for B-Bank, C-Bank, and D-Bank. Only in A-Bank, a fire floor is assumed to be the second floor, since the first (ground) floor is the floor of refuge. (See Figure 3)
2) A fire in one case is assumed to occur on the bottom floor within one of four parts of a building, but not to occur in two or more parts simultaneously.
3) As the service bank is higher, the constant velocity of elevators in each bank is naturally faster according to actual conditions in the building that is simulated. Specifically, the constant velocity of elevators is 4m/s, 5m/s, 6m/s, and 7m/s for A-Bank, B-Bank, C-Bank, and D-Bank respectively. The constant velocity of emergency-use elevators is set to be 3m/s.
4) In the bank where a fire occurs, only emergency-use elevators that are fire/smoke proof are available for elevator evacuation. In other banks, occupants can use regular elevators for their evacuation, but they cannot use emergency-use elevators because of the priority use by the occupants in the fire bank.
5) Emergency operational modes of elevator service are assumed to be two patterns such as;

   Mode(a) :

   For the bank where a fire occurs, elevators start from the first floor and go up directly to the floor just above a fire floor and next go to the second floor above a fire floor, and then go up directly to the highest floor within the bank. After then, elevators descend from the highest floor to lower floors gradually until they reach the third floor above the fire floor and then they directly descend to the first floor.

Mode(b) :

For banks other than a fire bank, elevators start from the first floor and go up directly to the highest floor within the bank and then elevators descend from the highest floor to lower floors gradually until they reach the bottom floor within the bank. After then, they directly descend to the first floor.

During the above operation process, once an elevator is filled up to its capacity, it does not receive further passengers and descends directly to the first floor. After it drops passengers off on the first floor, then it moves up again directly to the higher priority floor where there is any evacuee waiting for an elevator. The elevator service for evacuation continues until no evacuee waits.

6) The occupants on a fire floor are assumed to move down by stairs to the floor just below the fire floor. Therefore, this occupant load is added to that of the floor just below the fire floor in the evacuation calculation.

7) No influence by fire and smoke is considered during the evacuation. In this paper, the transportation efficiency is the main target of concerns.

4. Results and Discussion

4.1 Evacuation time by elevators in each bank and evacuation time by egress stairs.

Figure 4 shows the evacuation time by elevators by each bank and evacuation time by egress stairs for a whole building as well as for occupants in D-Bank, when a fire occurs on the bottom floor in the D-Bank. Here, the evacuation time by elevator in A-Bank, B-Bank, and C-Bank is calculated based on the premise that the occupants in the floors in these banks can use regular elevators (8 in each bank) for their evacuation. And, the regular elevators are operated by the emergency operation mode(b) that is stated earlier in section 3.3. In the D-Bank, the occupants can use only emergency-use two elevators that are operated by the emergency operation mode(a). The evacuation time by egress stairs here is calculated for the two patterns such as;

(i) All occupants in a whole building use two fire/smoke proof egress stairs, and

(ii) Only occupants on the floors in a fire bank use two fire/smoke proof egress stairs.

As seen in **Figure 4**, the dominant evacuation time by elevators is the evacuation time of D-Bank (6,122 seconds), because the occupants can use only two emergency-use elevators. By the way, the time of evacuation by two egress stairs for a whole building (Pattern(i): 4,323 seconds) is smaller than the evacuation time by emergency-use elevators only for D-Bank (6122 seconds), but is much larger than the evacuation time by regular elevators for each of A-Bank, B-Bank, and C-Bank. However, if we see the evacuation time by egress stairs for occupants only on the floors in D-Bank (Pattern(ii): 1,725 seconds), it is far smaller than evacuation time by two emergency-use elevators and moreover it is not so much different from even the evacuation time by eight regular elevators in each bank. This tells that evacuation by elevators is not always faster than evacuation by stairs, and it rather could be less favorable than evacuation by stairs according to conditions.

Then, in **Figure 5**, evacuation times by two emergency-use elevators, by eight regular elevators, and by two egress stairs are shown for each bank of A-Bank, B-Bank, C-Bank, and D-Bank respectively, assuming a fire floor in each corresponding bank. And also, evacuation time by egress stairs for a whole building is put for reference in the bottom. Fire/smoke proof emergency-use elevators are naturally much safer in a fire than regular elevators because they have an attached vestibule and emergency electricity supply, but the number (hence capacity) of emergency-use elevators is limited and their speed is slower than regular elevators. Therefore, if all occupants in each bank try to use emergency-use elevators for their evacuation, it takes much longer time than the cases of evacuation by regular elevators and also by egress stairs in each bank as shown in **Figure 5**.

By the way, evacuation time by egress stairs is quite similar to that by regular elevators in each bank and further the evacuation by egress stairs must be much safer than the evacuation by regular elevators. Therefore, it is recommended that most of general people on the floors in a fire bank should better use two fire/smoke proof egress stairs except the people who have difficulty to use stairs in their evacuation, while the occupants other than in a fire bank may use regular elevators if their safety operation is secured.

4.2 Comparison of transportation efficiency between two operational modes of emergency-use elevators.

In this section, assuming that a fire occurs on the bottom floor in D-Bank, transportation efficiency of the two operational modes of emergency-use elevators are compared in terms of the total evacuation time (T_{evac}) and the total sum of products of certain waiting time and number of people that have such waiting time ($T_{wait}=\Sigma(waiting\ time * number\ of\ people)$). Here, two operational modes are the mode(a) that priority is given to the floors above a fire floor first and the mode(b) that priority is given to the highest floor first, both of which are described in more detail in the section "3.3 Premises for case study" in this paper. From **Figure 6**, the evacuation completion times (T_{evac}) of the two operation modes are just same. And, the elevator operation mode(a) is only a little more preferable than the operation mode(b) in terms of the total sum of products of waiting time and number of people (T_{wait}), which is introduced for the consideration of potential exposure of occupants to smoke. However, by these simple indices, we cannot distinguish the preference between these two operational modes. Therefore, for this purpose, we should take into account the influence of smoke spread in conjunction with floor height and/or time lapse after ignition in further studies in the future.

4.3 Comparison of efficiency between evacuation by emergency elevators and evacuation by egress stairs as a function of the ratio of elevator use on the floors in D-Bank.

To see the change of efficiency of evacuation by elevators along with the population of elevator use, we compared evacuation completion time between the

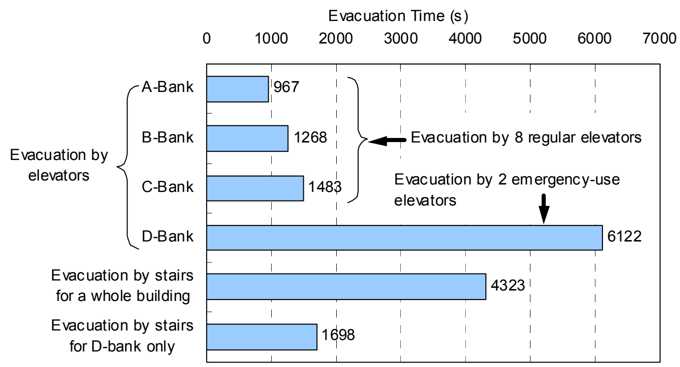

Figure 4 Evacuation time by regular elevators in A-Bank, B-Bank, C-Bank, and, and by emergency-use elevators in D-Bank and evacuation time by egress stairs for a whole building as well as only for D-Bank when a fire occurs on the bottom floor in the D-Bank.

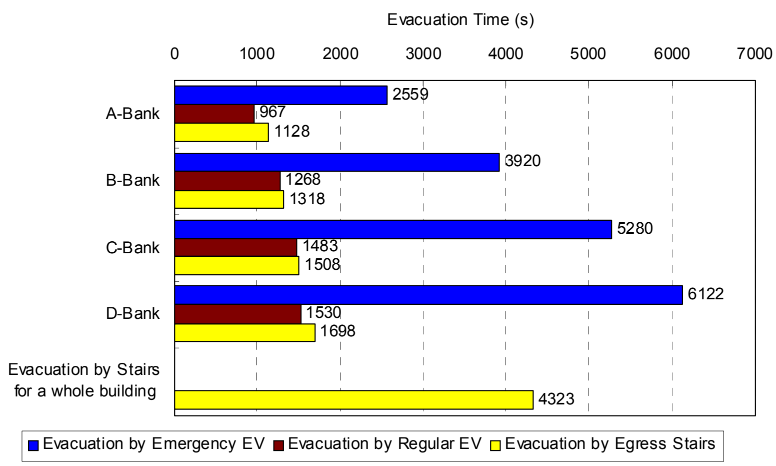

Figure 5 Evacuation time by elevators and by egress stairs in each bank and evacuation time by egress stairs for a whole building.

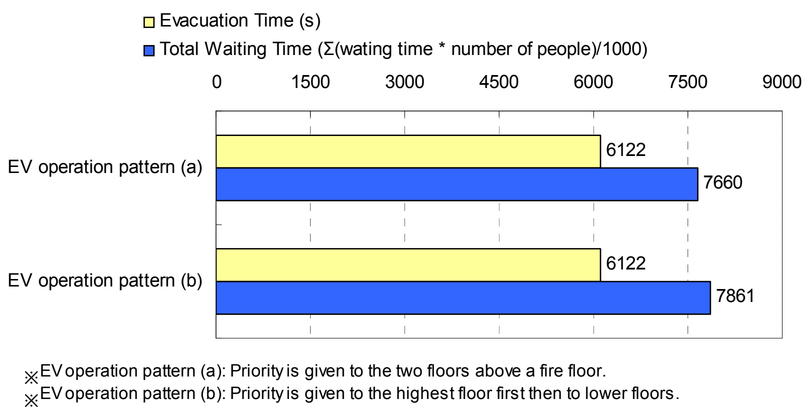

Figure 6 Comparison of transportation efficiency between two operation modes of emergency-use elevators for D-Bank assuming a fire in on the Bottom Floor in the D-Bank.

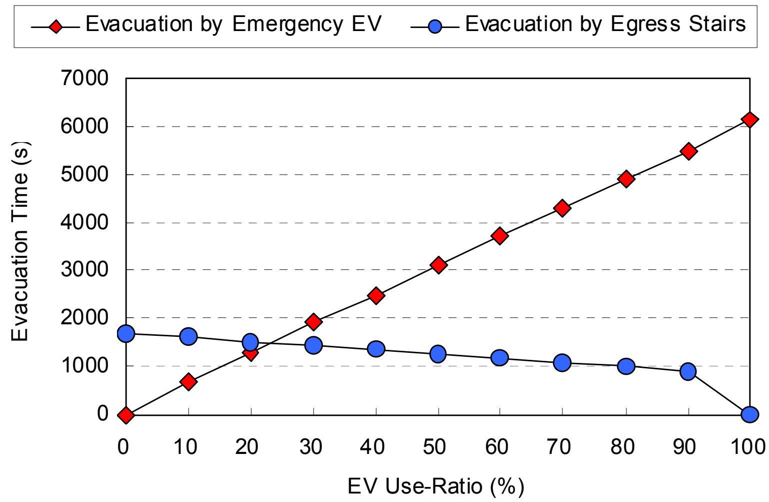

Figure 7 Comparison of evacuation completion time between the evacuation by emergency elevators and the evacuation by egress stairs as a function of the ratio of elevator use in D-Bank.

evacuation by emergency elevators and the evacuation by egress stairs as a function of the ratio of elevator use among the occupants in D-Bank, assuming that a fire occurs in D-Bank. **Figure 7** shows the evacuation completion time by emergency elevators and by egress stairs respectively for the cases, in which the ratio of elevator use of occupants is changing from 0% to 100% by 10% on the floors in D-Bank.

The evacuation completion time by egress stairs is ranging from 1,698 seconds to 910 seconds from 0% to 90% in elevator-use ratio. This is because the evacuation completion time by stairs is determined by the sum of travel time from the highest (53 story) to the first floor (ground floor) without congestion and the time of passage in stairs in the congestion dominated by the flow rate within the stairs, which is in proportion to the number of occupants who use the stairs for their evacuation.

On the other hand, the evacuation completion time by emergency-use elevators is increasing steeply in proportion to the ratio of elevator use, which is ranging from 0 second to 6,122 seconds. From this figure, it is seen that the lines of evacuation times by emergency-use elevators and by egress stairs are crossing around 25% in elevator-use ratio and therefore it is suggested that the evacuation by elevators is preferable only if a small part of occupants such as 25% or less of the occupants on the floors in D-Bank use emergency elevators that are available even in a fire.

5. Concluding Remarks

In order to examine the feasibility of elevator evacuation using a typical high-rise building, we conducted case studies with our simulation model of elevator operation and the model for evacuation by stairs, mainly focusing upon the efficiency of transportation of occupants. Although within the compass of the conditions of elevator service operation described in this paper, the results of case studies are summarized as follows.

1) If all occupants in each bank try to use emergency-use elevators for their evacuation, it takes much longer time than the cases of evacuation by regular elevators as well as the cases by egress stairs in every bank. On the other hand, evacuation time by egress stairs is quite similar to that by regular elevators in each bank. As evacuation by egress stairs is much safer than the evacuation by regular elevators, so it is recommended that most of general people on the floors in a fire bank should better use fire/smoke proof egress stairs except the people who have difficulty to use stairs in their evacuation.

2) We could not distinguish a clear difference in terms of transportation efficiency between the two operational modes of emergency-use elevators such as the mode(a) that priority is given to the floors above a fire floor first and the mode(b) that priority is given to the highest floor first. However, for this purpose, we should take into account the influence of smoke spread in conjunction with floor height and/or time lapse after ignition in further studies.

3) The evacuation completion time by emergency-use elevators is increasing at a great rate in proportion to the elevator use ratio among the occupants on floors in D-Bank, when assuming that a fire occurs in D-Bank. Also, to compare with evacuation by egress stairs, the advantage of elevators use in terms of transportation efficiency appears in certain limited conditions such as 25% or less of elevator use ratio among the occupants on floors in D-Bank.

In conclusion, if the elevator-use group can be designated only for a small part of occupants such as disabled people, it would be effective for those people to use fire/smoke proof elevators in evacuation. However, for other general people, it would be better to use egress stairs for their evacuation in most cases as well as to let the evacuation of disabled people by elevator more effective. In the future, the model improvement and further analyses are needed, considering variety of number and attributes of occupants, operational modes of elevators, hazard potential of smoke exposure to occupants, and so forth.

6. Acknowledgements

The authors gratefully acknowledge the courtesy of Mr. Kimio Tanabe, Mitsubishi Electric Corporation who provided advices on elevator operations and the collaboration of Dr. M. Nakano, Dr. K. Kubota, and Dr. Y. Ohmiya in making the data of evacuation behavior of the occupants in the Hiroshima Motomachi high-rise apartments fire.

References

1. A. Sekizawa, M. Ebihara, H. Notake, K. Kubota, M. Nakano, Y. Ohmiya, and H. Kaneko, "Occupants Behavior in response to the High-rise Apartments Fire in Hiroshima City", Proceedings of the First International Symposium on Human Behaviour in Fire, pp.147-156, Belfast, Northern Ireland, 1998.
2. S. Nakahama, Y. Ikehata, and H. Hayashi, "Study on Availability of Evacuation by an Elevator in Consideration of the Aged People - Example of the Hiroshima Motomachi High-rise Apartment Fire", Journal of Japan Association for Fire Science and Engineering (KASAI), Vol.48 No.3, pp. 44-49, in Japanese, June 1998.
3. A. Sekizawa, S. Nakahama, M. Ebihara, H. Notake, and Y. Ikehata, "Study on Feasibility of Evacuation by Elevators in a High-rise Building"—Case Study for

the Evacuation in the Hiroshima Motomachi High-rise Apartments--, Proceedings of the Second International Symposium on Human Behaviour in Fire, pp.65-76, Boston, USA, 2001.